Pomeron contribution to Spin-flip[*]

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Abstract

The pp polarization data confirm the presence of a diffractive-like (Pomeron) contribution in the spin flip amplitude. The extrapolation to RHIC energies does not appear very promising.

1   Introduction

Many years ago [1], one of us noticed that earlier high energy polarization data suggested a diffractive contribution in the spin-flip πp amplitude at high energy which becomes evident when the kinematical zero is removed. This contribution manifests itself in a "*reduced*" spin-flip amplitude which is peaked in the forward direction and which does not vanish when the energy increases. In Ref. [1] it was explicitly noticed that, once the kinematical zero is reduced, all partial waves act coherently in the small angle domain as it is typical of diffractive events [2] and the following statement was made: " *the residual spin-flip amplitudes behave very much like spin-non-flip amplitudes at high energies and exhibit a pronounced forward peak which is largely independent of the particular elastic reaction chosen*". This conclusion was reinforced by the analysis of similar pp data [3] when they became available. In this case, the situation is complicated by the existence of five independent helicity amplitudes in terms of which the polarization P (also called transverse single-spin asymmetry [4]) is defined as

$$P = 2\frac{\text{Im}[(\phi_1 + \phi_2 + \phi_3 - \phi_4)\phi_5^*]}{[|\phi_1|^2 + |\phi_2|^2 + |\phi_3|^2 + |\phi_4|^2 + |\phi_5|^2]}, \qquad (1)$$

where ϕ_1, ϕ_3 are spin-non-flip amplitudes, ϕ_2, ϕ_4 are double spin-flip amplitudes and ϕ_5 is a single spin-flip amplitude.

In this work we are interested on high energy and not too high t so that we can concentrate the analysis on the main aspects of the spin-flip amplitude for

pp scattering in the diffractive region. In [4] it was analyzed the magnitude of ϕ_2 and ϕ_4 with respect to the spin-non-flip amplitudes and reasonable arguments were given concerning the linear dependence in t for ϕ_2 ($\phi_2 \propto t$ when $t \to 0$). A similar dependence was also utilized in another work where the impact parameter space was used [5]. Neglecting ϕ_2 and ϕ_4 in this work, we write [3, 6]

$$\phi_1 + \phi_3 \sim g(s,t), \quad \phi_5 = h(s,t) \tag{2}$$

where $g(s,t)$ and $h(s,t)$ are *effective* spin-non-flip and spin-flip amplitudes, respectively. We then have [3, 6]

$$P = 2\frac{\mathrm{Im}[g(s,t)h^*(s,t)]}{|g(s,t)|^2 + |h(s,t)|^2}. \tag{3}$$

Today, a rather considerable amount of data at higher energies has been gathered [7] in the relatively small angle domain and new perspectives are being opened by the coming in operation of the Relativistic Heavy Ion Collider (RHIC), the ideal machine to study polarization in high energy collision processes [8].

In addition, our phenomenological information on the spin-non-flip amplitude is today much more complete and this can be used to reduce the uncertainties in the analysis.

Using an explicit parametrization for the pp spin-non-flip amplitude [9] whose parameters have been calculated against all high energy pp and $\bar{p}p$ data (except polarization), we analyze the structure of the reduced spin-flip contribution. The following conclusions are reached analyzing the data:

a) The (reduced) spin-flip amplitude has the typical peak in the forward direction which characterizes diffractive amplitudes or (which amounts for the same), has a non-negligible Pomeron $I\!P$ contribution which

b) appears of comparable size as in the non-flip part[1] or not much smaller in the forward region, a characteristic already noticed at lower energies [3];

c) the best way to fit the data is compatible with the same energy dependence in the spin-flip and in the spin-non-flip[2].

d) A zero of the polarization is predicted in the dip region; this zero recedes toward zero as the energy increases just as the dip position does (in fact, it is the zero of the spin-non-flip amplitude that determines the zero of the polarization according to us);

e) the extrapolation to RHIC energies appears not very easy to measure.

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[1] The data [7] are analyzed introducing the **effective** spin-flip amplitude reduced by explicitly factoring out the kinematical zero. For various reasons, related to the way one removes the kinematical zero either by $\sin\theta$ or $\sin(\theta/2)$ or $\sqrt{-t}$, it is difficult to compare our results for the fraction of the Pomeron $I\!P$ contribution to the spin-flip amplitude with calculations from other works using different definitions for the single spin-flip amplitude. So, we adopt the notation of Refs. [1, 3] and we do not compare the results with other approaches.

[2] As we will see, a slower growth with energy of the spin-flip is not entirely ruled out but appears quite unlikely.

2   Definition of the amplitudes

The pp spin-non-flip amplitude is

$$a_{pp}(s,t) = a_+(s,t) - a_-(s,t) \qquad (4)$$

with

$$a_+(s,t) = a_{I\!P}(s,t) + a_f(s,t) \quad , \quad a_-(s,t) = a_O(s,t) + a_\omega(s,t) \qquad (5)$$

where $a_P(s,t)$ and $a_O(s,t)$ are the $I\!P$ (Pomeron) and Odderon amplitudes respectively and $a_f(s,t)$ $[a_\omega(s,t)]$ are the even [odd] secondary Reggeons[3]. These different amplitudes are taken directly from Ref. [9] and their explicit forms are listed in Appendix A together with the values of their parameters.

In the effective spin-flip amplitude, eq. (2), we neglect the contribution of secondary Reggeons and the simplest minded parametrization is chosen[4]

$$\begin{aligned} h(s,t) &= a^{sf}(s,t) = (i\gamma_1 + \delta_1)\sin\theta\,\tilde{s}^{\alpha^{sf}(t)}e^{\beta_1 t}\Theta(|t| - 0.5) \\ &+ (i\gamma_2 + \delta_2)\sin\theta\,\tilde{s}^{\alpha^{sf}(t)}e^{\beta_2 t}\Theta(0.5 - |t|), \end{aligned} \qquad (6)$$

where $\tilde{s} = \frac{s}{s_0}e^{-i\pi/2}$, Θ is the step function and we assume $s_0 = 1$ GeV^2 as in [9].

To start with, we will take $\alpha^{sf}(t)$ to have exactly the same $I\!P$ contribution of a_{pp}, i.e.

$$\alpha^{sf}(t) = \alpha_{I\!P}(t) = \alpha_{I\!P}(0) + \alpha'_{I\!P}t \qquad (7)$$

where $\alpha_{I\!P}(0)$ and $\alpha'_{I\!P}$ are found in Appendix A. The data at $\sqrt{s} = 13.8$, 16.8 and 23.8 GeV (a total of 64 points) are used in the fit and the values of the parameters, together with the χ^2 are listed in Table 1.

γ_1	2.55	γ_2	0.18
δ_1	4.80	δ_2	0.45
β_1 (GeV^{-2})	6.25	β_2 (GeV^{-2})	2.30
$\chi^2/d.f. = 1.1$			

Table 1: Results from fitting polarization data at $\sqrt{s} = 13.8$, 16.8 and 23.8 GeV with eqs. (6) and (7).

In Fig. 1 we show the polarization data together with our reconstruction. As a check of the validity of our solution, Fig. 2 shows how it accounts for the data at $\sqrt{s} = 19.4$ Gev (not used in the fit).

Some considerations are in order:

a) Our result, i.e. our effective spin-flip amplitude cannot be extended to $|t|$ values much higher than few GeV^2 because the spin-non-flip amplitude utilized is at the Born level [9] and its description in the region after the dip ($|t| > 1.5$ GeV^2) is not very good; for this, it would be necessary to

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[3]Actually, a_f embodies both f and ρ contributions (and a_ω both ω and a_2).

[4]We have found that a much better result is obtained if the very small $|t|$ domain is singled out. Quite arbitrarily, we take $|t| \simeq 0.5$ GeV^2 as the limit for that region.
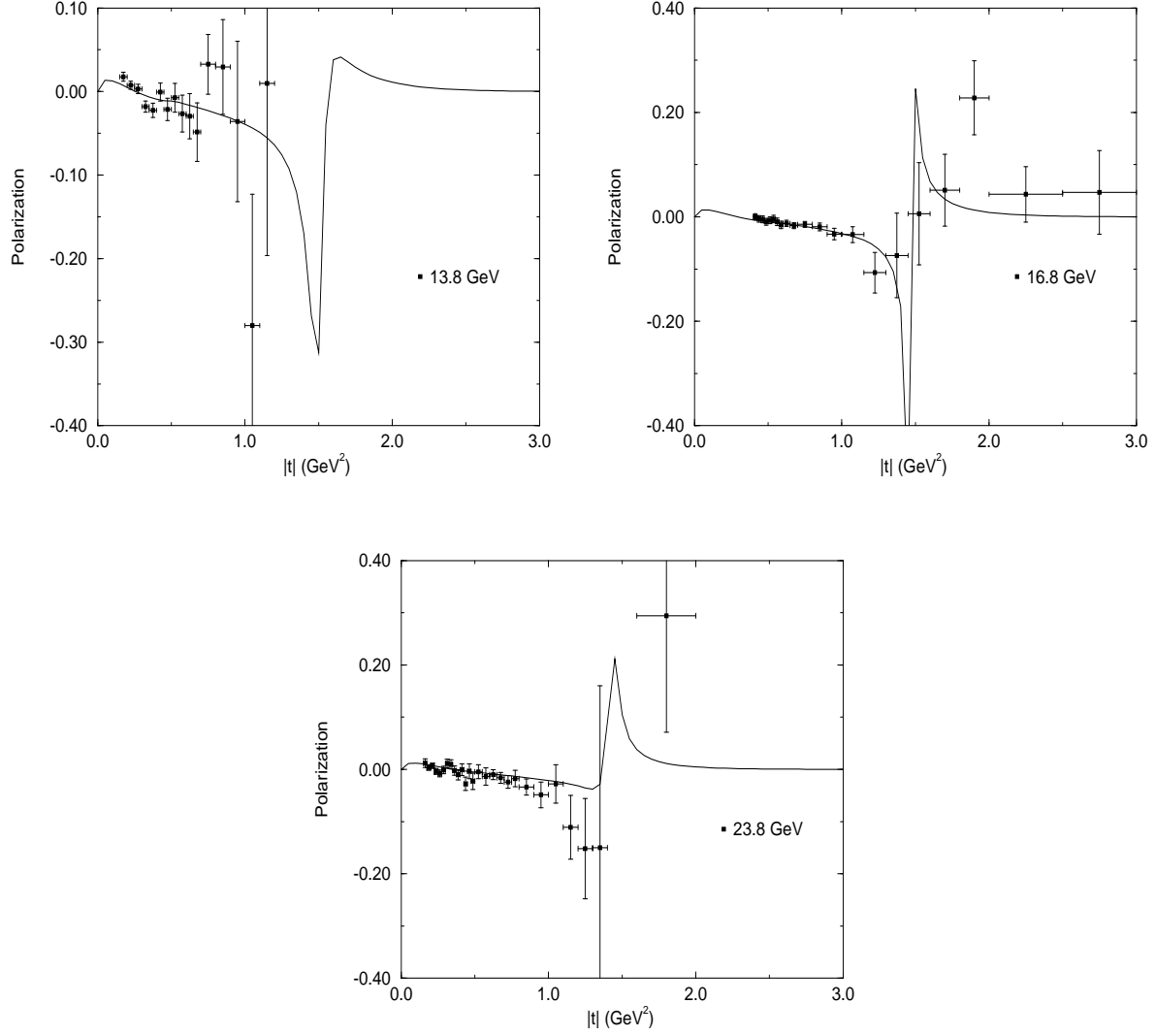
Figure 1: Results from fitting (see Table 1) at the energies of 13.8, 16.8 and 23.8 GeV.

adopt the more sophisticated eikonalized version. Anyway, the t-region of interest for RHIC is up to 1.5 GeV^2 [8] so we can concentrate the study on the not too high t-region;

b) the solution we found shows a considerable $I\!\!P$ contribution in the spin-flip amplitude. We will reconsider this point immediately below.

c) As a check that our introduction of the spin-flip amplitude has not spoiled the fit of Ref. [9], we show $d\sigma/dt$ in Fig. 3 at various energies.

d) The (small $|t|$) slope of the spin-flip amplitude $\beta_1 = 6.25$ GeV^{-2} is some-
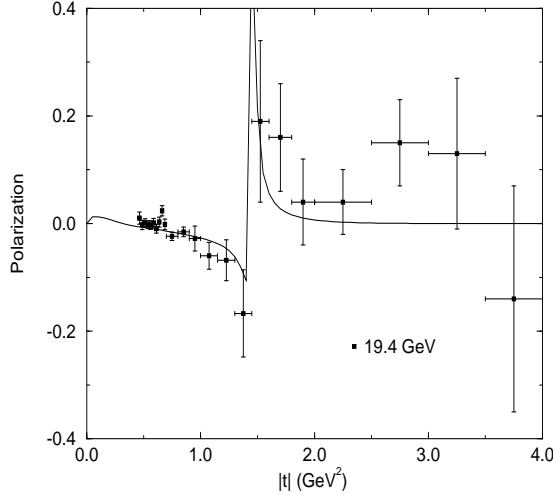
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Figure 2: The prediction for polarization at 19.4 GeV (not used in the fit) compared with the experimental data on that energy.

what different from the one that had been determined in Refs. [3] but the present parametrization is considerably more elaborate and not directly comparable[5].

e) The extrapolation of our solution to 50 and 500 GeV predicts the polarization shown in Fig. 4. As one can see, it will be very hard to measure such a polarization.

One open question remains the possibility that $\alpha^{sf}(0)$ be not the same as in the spin-non-flip amplitude. If $\alpha^{sf}(0)$ is left free to vary, one can still fit the data but the improvement on the description of the polarization is very small and visible only at small-t for $\sqrt{s} = 13.8$ GeV (see Fig. 5) while at other energies the differences in the description are irrelevant for the quality of the fitting (in fact, the $\chi^2/d.f.$ is practically the same in both cases) as can be seen in Fig. 5 and 6. Table 2 shows the values obtained for the parameters of eq. (6) when $\alpha^{sf}(0) \neq \alpha_P(0)$. There appears a strong change of these parameters compensated by the new $\alpha^{sf}(0)$ and, as a result, the polarization is the same up to $\sqrt{s} = 23.8$ GeV but when we look at RHIC energies the polarization predictions are even smaller (Fig. 7), for example at $\sqrt{s} = 500$ GeV the result is one hundred times smaller making essentially impossible to detect these values experimentally. At this point it is hard to conclude if those new values (Table 2) are an improvement of the fitting or another local minimum. Since the larger number of fitted parameters did not improve the description of polarization data we conclude that a slower growth with energy of the spin-flip amplitude is quite

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[5]The factor $\tilde{s}^{\alpha(t)}$ generates a $|t|-$dependent factor $\exp(+\alpha' t \ln s)$ which cooperates with $\exp(\beta_1 t)$.
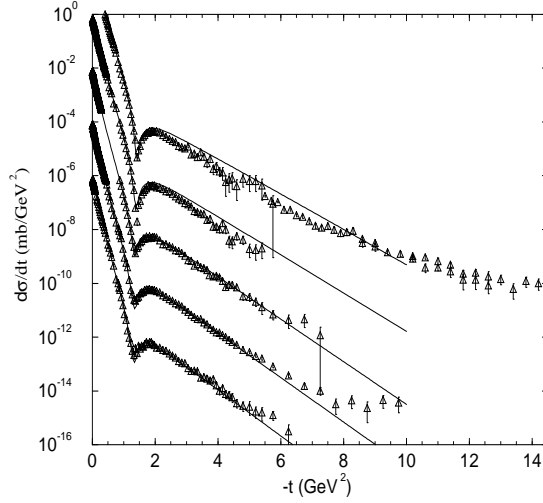
Figure 3: The differential cross section obtained in this work taking into account the spin-flip amplitude. The highest set of data correspond to 23.5 and 27.4 GeV grouped together. The other sets (multiplied by powers of 10^{-2}) are 30.5, 44.6, 52.8 and 62 GeV.
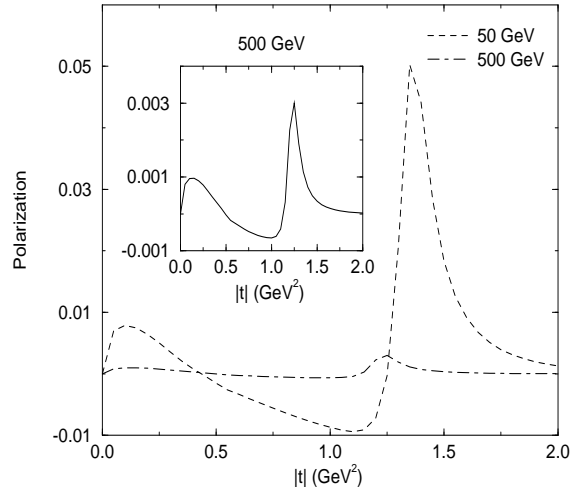

Figure 4: The polarization predictions for 50 and 500 GeV with a detailed view of the 500 GeV (parameters from Table 1) in the inset.

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unlikely as already mentioned. We do not show $d\sigma/dt$ calculated with the values of Table 2 because it is indistinguishable from Fig. 3.

$\alpha_P^{sf}(0) = 0.377$			
γ_1	-300	γ_2	-16
δ_1	443	δ_2	19
β_1 (GeV^{-2})	7.84	β_2 (GeV^{-2})	2.32
$\chi^2/d.f. = 1.1$			

Table 2: Results for eq. (6) with $\alpha^{sf}(0) \neq \alpha_P(0)$.
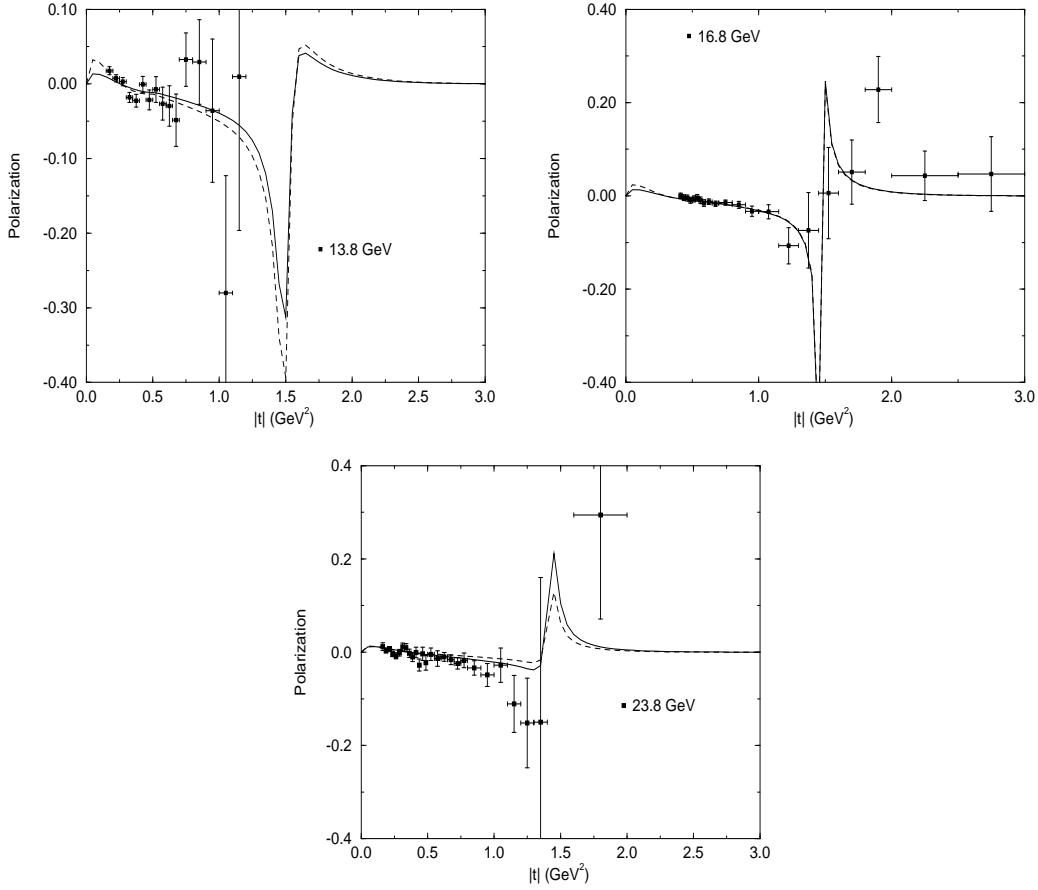

Figure 5: Results from fitting the data at 13.8, 16.8 and 23.8 GeV with values from Table 2 (dashed line) compared to results from Table 1 (solid line).
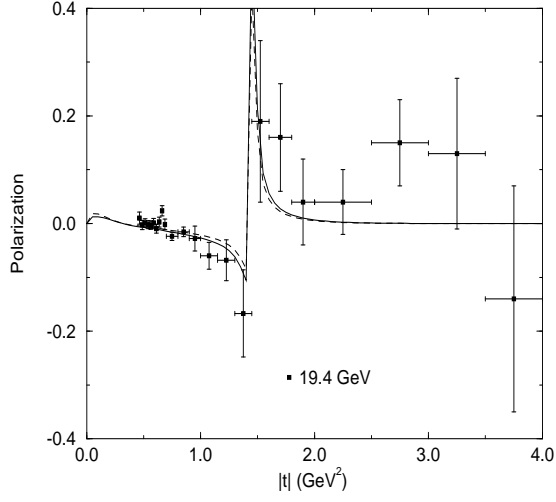
Figure 6: The prediction for polarization at 19.4 GeV compared with the experimental data using parameters of Table 2 (dashed line) and the result from Table 1 (solid line).
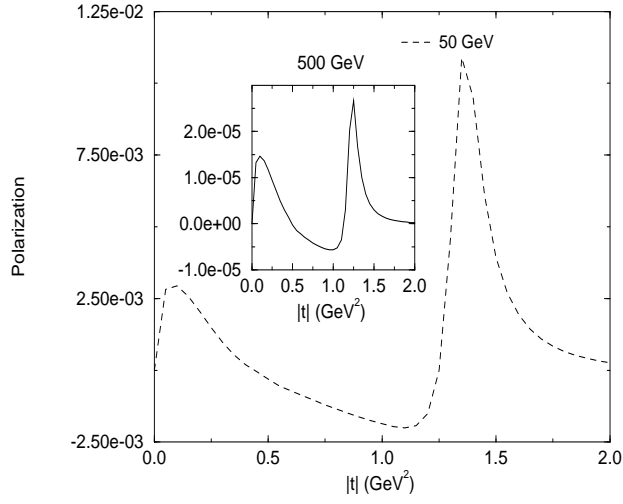

Figure 7: The polarization predictions for 50 and 500 GeV using the parameters of Table 2. A detailed view of the 500 GeV is shown in the inset.

3   Conclusions

The conclusions have already been anticipated but, once more, spin effects appear extremely interesting: the spin-flip amplitude confirms the diffractive-like

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behavior that had been anticipated by the pioneer analysis of long ago [1, 3]. Analyzing the reduced spin-flip amplitude (removing the kinematical zero by the $\sin\theta$ factor in eq. (6)), we find that it is comparable in size with the spin-non-flip amplitude as already noticed in [3]. The spin-flip amplitude can be represented with a very simple form and the general features of the polarization data are well described if the same energy dependence in spin-flip as in spin-non-flip Pomeron amplitude is utilized. The spin-flip amplitude appears to have two different regimes, a fast decrease with $|t|$ at small-t with $\beta_1 = 6.25$ GeV^{-2} followed by a slower decrease at medium-t ($\beta_1 = 2.30$ GeV^{-2}). We calculated the polarization at RHIC energies and predicted two zeros, the last one is determined by the zero of the spin-non-flip amplitude followed by a local maximum. However, the magnitude of the polarization becomes so small when the energy increases that it may be very difficult to perform the experimental measurements at $\sqrt{s} \sim 500$ GeV.

It would be possible to improve the description of the data with more elaborated forms for spin-non-flip (by eikonalizing it [9], for example) and spin-flip (introducing non-asymptotic effects by secondary Reggeons) amplitudes but the main aspects of our analysis would be the same for small-t (where the Born amplitudes work well) and higher energies (the region of Pomeron dominance).

APPENDIX

A   The spin-non-flip amplitude

The spin-non-flip amplitude utilized in this work is

$$a_{pp}(s,t) = a_+(s,t) - a_-(s,t), \tag{8}$$

where

$$a_+(s,t) = a_{I\!P}(s,t) + a_f(s,t) \text{ and } a_-(s,t) = a_O(s,t) + a_\omega(s,t). \tag{9}$$

The expressions for the two Reggeons used in [9] are

$$a_R(s,t) = a_R\tilde{s}^{\alpha_R(t)}e^{b_R t}, \ \alpha_R(t) = \alpha_R(0) + \alpha'_R t, \ (R = f \text{ and } \omega) \tag{10}$$

with $a_f(a_\omega)$ real (imaginary).

For the Pomeron, the non spin-flip amplitude is

$$a_{I\!P}^{(D)}(s,t) = a_{I\!P}\tilde{s}^{\alpha_{I\!P}(t)}[e^{b_{I\!P}(\alpha_{I\!P}(t)-1)}(b_{I\!P} + ln\tilde{s}) + d_{I\!P}ln\tilde{s}] \tag{11}$$

while for the Odderon, we choose

$$a_O(s,t) = (1 - \exp(\gamma t)) * a_O \tilde{s}^{\alpha_O(t)} [e^{b_O(\alpha_O(t)-1)}(b_O + ln\tilde{s}) + d_O ln\tilde{s}], \qquad (12)$$

and again $a_{I\!P}(a_O)$ real (imaginary). We use $\alpha_i(t) = \alpha_i(0) + \alpha'_i t$ where $i = I\!P, O$.

Our definition for the amplitude follows [9] so that

$$\sigma_t = \frac{4\pi}{s} \text{Im}\{a_{pp}(s, t = 0)\}, \qquad (13)$$

$$\frac{d\sigma}{dt} = \frac{\pi}{s^2}(|a_{pp}(s,t)|^2 + |a^{sf}(s,t)|^2). \qquad (14)$$

In this work we retain the same parameters for the spin-non-flip amplitude as in [9] and we keep them fixed while fitting the parameters of the spin-flip amplitude. We utilize the dipole model at the Born level since great part of the polarization data is contained in the t-domain corresponding to the region before the dip in $d\sigma/dt$ (well described without eikonalization). The values of the parameters of the spin-non-flip amplitude are shown in Table 3.

	Pomeron	Odderon	f-Reggeon	ω-Reggeon
$\alpha_i(0)$	1.071	1.0	0.72	0.46
α'_i	0.28 GeV^{-2}	0.12 GeV^{-2}	0.50 GeV^{-2}	0.50 GeV^{-2}
a_i	-0.066	0.100	-14.0	9.0
b_i	14.56	28.10	1.64 GeV^{-2}	0.38 GeV^{-2}
d_i	0.07	-0.06	-	-
γ	-	1.56 GeV^{-2}	-	-

Table 3: Parameters of the dipole model at the Born level [9] with $i = I\!P, O, f, \omega$.

To calculate the polarization we utilized the form

$$P = 2\frac{\text{Im}(a_{pp}(s,t)(a^{sf}(s,t))^\star)}{|a_{pp}(s,t)|^2 + |a^{sf}(s,t)|^2}; \qquad (15)$$

where the star on the numerator means the complex conjugate.

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